Abstract

Digital models of key outcrops of (exceptionally well exposed, continuous and structurally intact) end-member carbonate systems provide exact and quantitative information on spatial sedimentary lithofacies trends and juxtaposition rules as well as associated stratal anatomy, properties in the subsurface that are typically unknown and can only be guessed at.

Outcrop studies at Djebel Bou Dahar, Morocco, yield insight into facies and stratigraphy for the platform top and steep slopes of an isolated carbonate platform, 34 by 6 km, that serves as an analog for reservoirs in the Caspian Basin and elsewhere. Themes are the extensional tectonic setting, relatively minor role of eustatic sea level on sedimentation, a shallow platform dominated by tidal flat deposits, the evolution from ramp to flat topped platform and retrograding margin with allochthonous deposition and extensive syndepositional fracturing.

Amellago is a high-quality outcrop of an early Jurassic ramp system, nearly 35 km in dip direction, that is an analog for Mesozoic to Tertiary carbonate ramp reservoirs, particularly in the Middle East. Amellago is an alternating ooid (lowstand) – and mud (highstand)-dominated ramp showing the interaction of both eustacy and tectonics.

Field observations combined with satellite imagery and LIDAR were used to capture lithofacies patterns and stratal architecture. Final (interpreted) products following the isolated platform and ramp studies are a digital catalog with spatial data on grand scale and smaller (reservoir) scale, lithofacies elements, and stratal anatomy of two key carbonate settings. The resulting models can be queried and contrasted/compared with subsurface carbonate reservoirs to provide solutions and/or alternatives.
Digital Outcrop Models of Carbonate Platform and Ramp Systems: Analogs for Reservoir Characterization and Modeling

Jeroen Kenter¹, Mitch Harris¹, Aurélien Pierre²

¹Chevron Energy Technology Company, San Ramon, U.S.A., jeroenkenter@chevron.com; ²Chevron Energy Technology Company, Aberdeen, U.K.

With contributions by:
Oscar Merino-Tomé, Klaas Verwer, Giovanna Della Porta, Xavier van Lanen, Erwin Adams, Dave Hodgetts, Frank Rarity, Marge Levy and many others
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Rationale

- Subsurface exploration and reservoir characterization require constant improvement of geostatistical modeling concepts and input data through digital models of exceptionally well exposed, continuous and structurally intact outcrops.
- Outcrops provide exact and quantitative information on spatial lithofacies trends and juxtaposition rules as well as associated stratal anatomy.
- Digital models generated by integrating traditional geological observations with LIDAR and RTK DGPS data as well as satellite imagery.
- Forward modeling (Dionisos) and geostatistical modeling techniques (GoCad stochastic and MPS/FDM) used to capture the spatial distribution and juxtaposition of key depositional rock types.
- Two examples: Isolated carbonate platform and mixed clastic-carbonate ramp, both in the Southern High Atlas, Morocco.
Investing in Outcrops

- The investment of significant resources and manpower for such analyses requires high quality and continuous outcrops.

- Representing end-members of carbonate systems that are relevant to the subsurface reservoirs.

- Two such carbonate systems were studied recently in collaboration with a number of academic institutions and are located in the southern High Atlas, Morocco:
  - the Djebel Bou Dahar isolated carbonate platform system
  - the Amellago mixed clastic-carbonate ramp system
  - both early Jurassic age, nucleated and evolved in slightly different tectonic regimes and physically only 100-125 km apart.
Outcrop to Digital Model Workflow - 1

- Outcrops bridge the resolution gap between seismic and well data.
- Digital tools (RTK DGPS, LIDAR, DEMs, satellite imagery, etc.) allow quantification of geologic outcrop features by utilizing spatial positioning.
- Digital outcrop models (DOMs) capture numerical spatial data of depositional rock types on a wide range of scales and represent the numerical observations at the intersection of the outcrop surface with the underlying geology.
- Often labeled as 3D data sets; in fact still pseudo 2D representation of “hard” data; require careful analysis to extract truly 3D information on structure and facies.
- Fit depositional surfaces, information from measured sections and mapped rock type zones using i.e VRGS (University of Manchester).
- Next transfer of the data set into a cellular domain – so-called “sgrid” - for static modeling (like in GoCad or Petrel) or forward modeling processes (i.e. Dionisos).
Different geostatistical tools can be applied to distribute the rock types in 3D away from the hard data areas and thereby fill the area of interest.

Once a fully populated model is generated geotechnical application may simulate transport properties in a semi subsurface condition.

Common geostatistical tools for simulating rock types are stochastic techniques or multiple point statistics (MPS/FDM), pixel-based and deterministic.

The first use variograms which have a major disadvantage in the general inability to simulate sedimentary trends or bodies and can not be conditioned to global rock proportions.

MPS/FDM allows such conditioning and is capable of simulating both depositional and diagenetic shapes, trends and associations between rock types.
Carbonate Systems from Outcrops

Outcrops imaged using aerial photography and/or satellite imagery
LIDAR and RTK DGPS hard data acquisition

Acquisition of field data and generation of DOMs
DOMs and capturing additional “soft” (interpreted) data

Capturing “soft” data using Petrel or VRGS
Stochastic simulations using variograms and object-based techniques

Platform interior – variograms only

Retrogradational slope – variograms and object-based
Multiple Point Statistics and Facies Distribution Modeling (MPS/FDM) simulations

- Training Image
- Probability Cube
- Facies Curve
- Simulation
Forward Modeling Simulations (Dionisos)
Djebel Bou Dahar Isolated Carbonate Platform

- Yields insight into facies and stratigraphy for the platform top and steep slopes of an isolated carbonate platform, 35 by 7 km
- Serves as an analog for reservoirs in the Caspian Basin, Black Sea, Turkmenistan and elsewhere
- Themes are the extensional tectonic setting, relatively minor role of eustatic sea level, dominated by tidal flat deposits, the evolution from ramp to flat topped platform and retrograding margin with allochtonous deposition and extensive syndepositional fracturing
- “Hard” geological data was captured by RTK DGPS, LIDAR and stored in a DOM
- Complex process of fitting key sequence stratigraphy surfaces and interpreting rock types (“soft” data) away from the control areas and measured sections is near completion
- Next, the resulting sgrid will be transferred to GoCad and MPS/FDM simulation for each of the six sequences will be performed
DBD - Overview

ASTER DEM and ORTHOIMAGERY
15 m spatial resolution

Intact slope profile

Eroded backstepping margin

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DBD – Traditional Geological Analyses

Depositional model for stage VI

3: Beginning of the drowning
Relatively open lagoon

2: Time interval of the platform-study window

1: Mid stage VI

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DBD – Painting Facies and Balancing Cross Sections

Facies captured from outcrop painted on DOM

Cross sections reconstructing stage boundaries in DOM
Spatially constrained intersections with stage boundaries and measured sections prior to fitting of surfaces
Amellago Ramp System

- High-quality early Jurassic outcrop of ramp system (35 km in dip direction) as analog for Mesozoic to Tertiary carbonate ramp reservoirs, particularly in the Middle East

- Alternating ooid (lowstand) – and mud (highstand) dominated ramp demonstrating the interplay of both eustacy and tectonics

- LIDAR imagery template for RTK DGPS measured sections and facies boundaries in inner-outer ramp sector

- Virtual Reality Geology Software (VRGS) allowed identification and registration of key surfaces, measured sections and facies transitions

- Currently modeled in Dionisos and utilized as a subsurface analog to reservoirs in the Middle East and elsewhere.

- Next is the generation of MPS/FDM simulations which will be expected by the fall of this year

- Results provide key morphometric data facies dimensions as well as on the juxtaposition and erosion rules between rock types
Amellago Ramp – Traditional Geological Analyses

Traditional photo pans and depositional concepts
Amellago Ramp – Generation of DOM using Lidar and satellite imagery

High res LIDAR foundation for capturing spatial “hard” data (top) and VRGS model extracting additional “soft” data like SSF surfaces, faults and facies boundaries.
Amellago Ramp – Forward Modeling (Dionisos)

Forward modeling of facies distribution but limited by conditioning to hard data.
Summary and Conclusions

- Field observations from these two areas combined with satellite imagery and LIDAR were used to capture lithofacies patterns and stratal architecture as DOMs.

- Final (interpreted) products are a digital catalog with spatial data on grand-scale and smaller (reservoir) scale, lithofacies elements and stratal anatomy of two key carbonate settings.

- Resulting models can be queried and contrasted/compared with subsurface carbonate reservoirs to provide solutions and/or alternatives.

- Such information is essential to improve industry concepts of geostatistical modeling using outcrops, sequence stratigraphy, prediction from seismic reflection data, and flow models for hydrocarbon reservoirs.